BILLIARDS: A Demonstration Mission for Hundred-Meter Class Near Earth Asteroid Disruption

Matthew Marcus - University of Maryland, College Park
Joshua Sloane - University of Maryland, College Park
Oliver Ortiz - University of Maryland, College Park
Brent Barbee - NASA Goddard Space Flight Center

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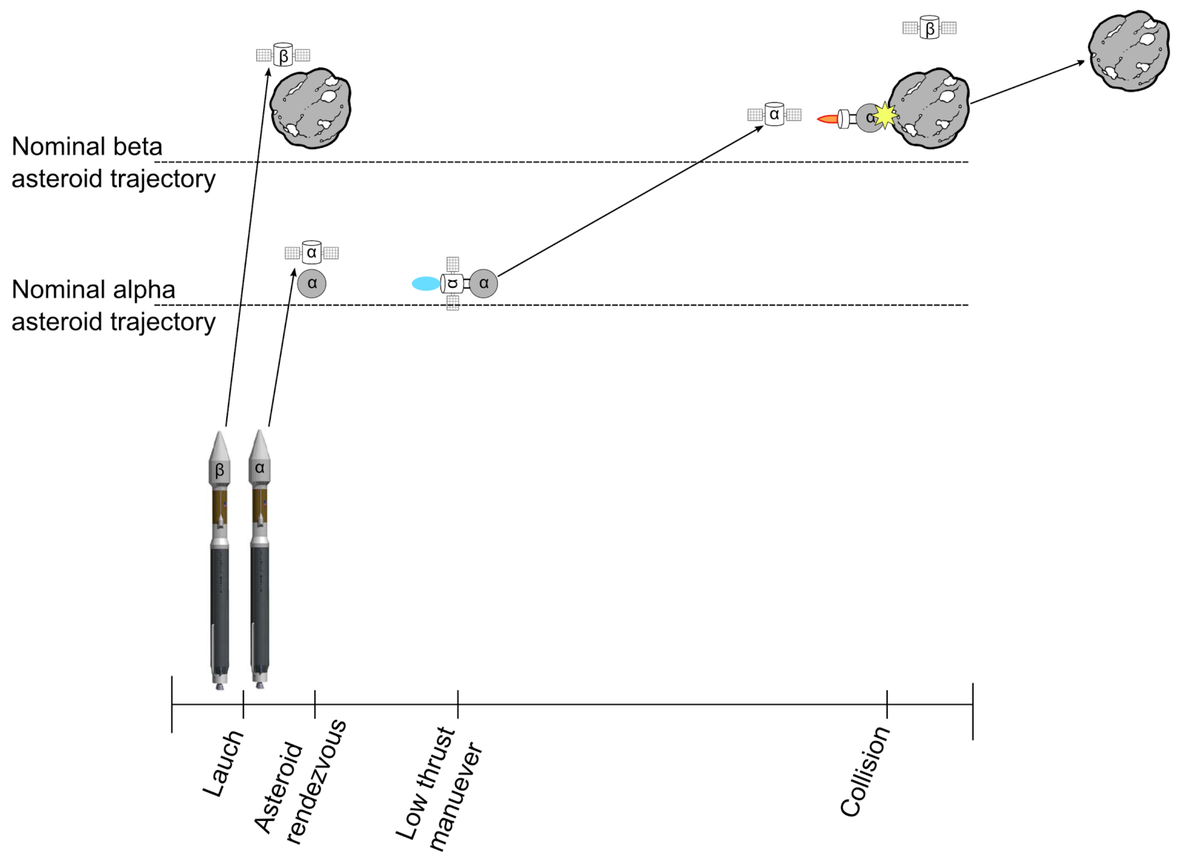
Introduction

Currently, no planetary defense demonstration mission has ever been flown. While Nuclear Explosive Devices (NEDs) have significantly more energy than a kinetic impactor launched directly from Earth, they present safety and political complications, and therefore may only be used when absolutely necessary. The Baseline Instrumented Lithology Lander, Inspector, and Asteroid Redirection Demonstration System (BILLIARDS) is a demonstration mission for planetary defense, which is capable of delivering comparable energy to the lower range of NED capabilities in the form of a safer kinetic impactor. A small asteroid (<10m) is captured by a spacecraft, which greatly increases the mass available as a kinetic impactor, without the need to bring all of the mass out of Earth's gravity well. The small asteroid is then deflected onto a collision course with a larger (~100m) asteroid. This collision will deflect or disrupt the larger asteroid. To reduce the cost and complexity, an asteroid pair which has a natural close approach is selected.

Concept of Operations

- Launch
- Asteroid rendezvous
  - Spacecraft rendezvous with small ~6m (alpha) asteroid
  - Option for second spacecraft to rendezvous with larger ~100m (beta) asteroid
- Low-thrust maneuver
  - Spacecraft performs a low thrust maneuver 12m/s place alpha asteroid on a collision trajectory with a 160m (beta) asteroid
- Collision
  - 36h prior to collision, the instrumentation module separates from the terminal guidance module
  - Instrumentation module moves to a safe location to observe the collision
  - Terminal guidance module applies impulsive trajectory correction maneuvers as exact beta asteroid position is determined



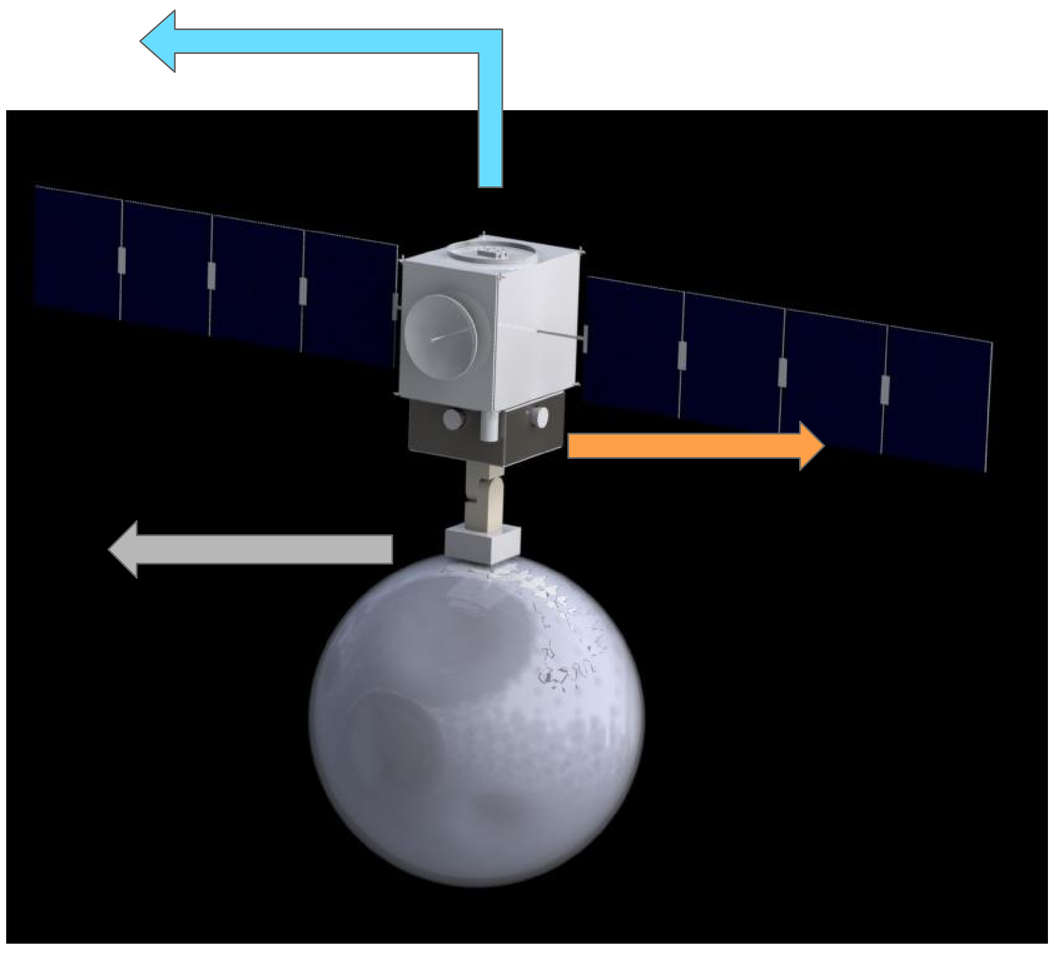
Spacecraft Design

Instrumentation Module

- Dry mass: 1000 kg
- Propellant mass: 800 kg
- 3x BPT-4000 Hall thrusters (0.25 N each)
- Production & Development cost: $538M

Capture Mechanism

- Mass: 310 kg
- Additional R&D cost: $64M
- Shown having captured 6m alpha asteroid
- Connected to terminal guidance module by gimbal
- Rendezvous with alpha at its pole, spin up to match rotation rate, capture with a claw/bag mechanism

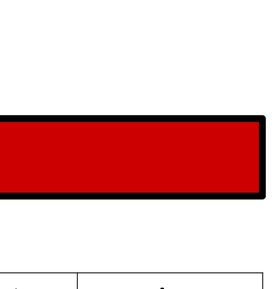


Terminal Guidance Module

- Dry mass: 687 kg
  - Including capture mechanism
- Propellant mass: 600 kg
- 5x R-4D bipropellant thrusters (490 N each)
- Production & Development cost: $334M

Terminal Guidance CONOPS

- Separates from instrumentation module 36h before collision
- Spins up alpha asteroid with rotation vector parallel to position vector from alpha to beta
- Nulls velocity normal to the rotation vector



Asteroid Selection

Alpha Asteroid - 2011 MD

- Orbit classification: Apollo
- a = 1.06 AU
- e = 0.0416
- i = 2.58 deg
- 6^{+4}_{-2} m diameter
- $1.1^{+0.7}_{-0.5}$ g/cm^3

Beta Asteroid - 2010 PR10

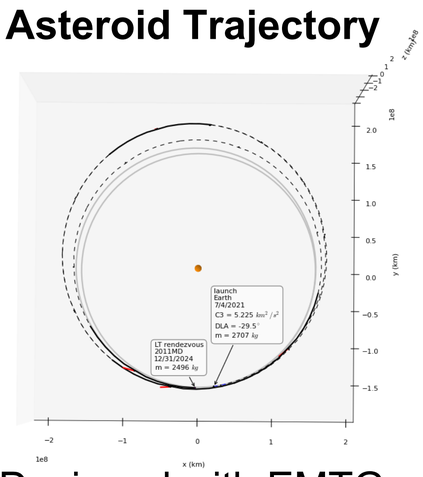
- Orbit classification: Amor
- a = 1.2 AU
- e = 0.18
- i = 9.2 deg
- 160^{+196}_{-80} m diameter

Close Approach

- Impact date: Jan 26, 2029
- Impact velocity: 6.6 km/s
- Beta asteroid disruption expected
  - Q = alpha asteroid kinetic energy / beta asteroid mass
  - Q* = energy needed for disruption
  - Expected Q/Q*: 9.0

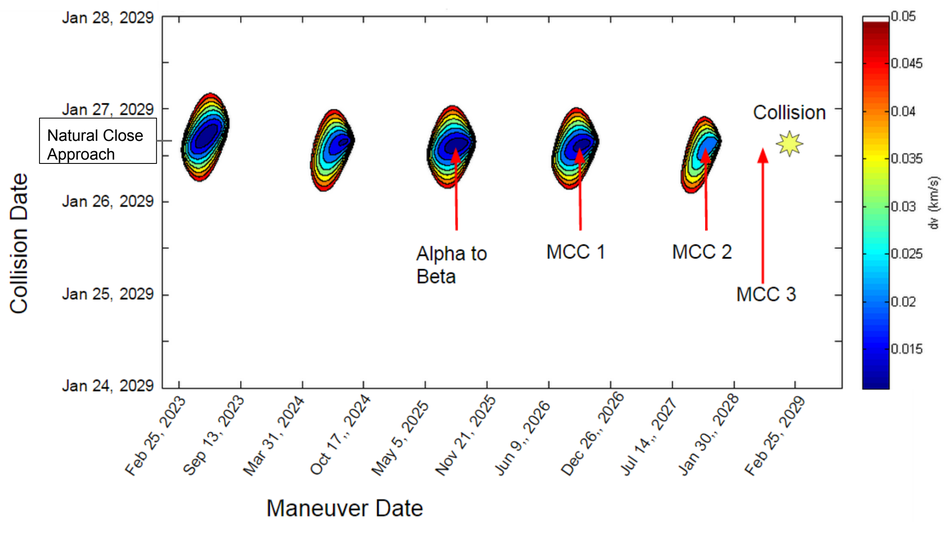
Trajectory Design

Earth to Alpha Asteroid Trajectory



Designed with EMTG

Alpha to Beta Asteroid Trajectory



Δv budget

Maneuver type	*Maneuver*	*Start Date*	*Δv*
Launch Falcon 9 v1.1 Instrumentation Module Terminal Guidance Module	Launch	July 4, 2021	C3 = 5.225 km^2/s^2
Low-thrust Instrumentation Module Terminal Guidance Module	Alpha Rendezvous	July 11, 2021 (L+7d)	1.6 km/s
Low-thrust Instrumentation Module Terminal Guidance Module Alpha Asteroid	Alpha Redirect	August 12, 2025	12.0 m/s
	Midcourse Corrections		19.2 m/s
High-thrust Terminal Guidance Module Alpha Asteroid	Terminal Guidance Maneuvers	January 25, 2029 (I-24h)	8 m/s